



# Comparison of AIRS Version-6 OLR Climatologies and Anomaly Time Series with those of CERES and MERRA-2

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AIRS Science Team Meeting

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MERRA-2 team for making the data available to us

# Topics to be Covered

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- Inter-comparison of AIRS Version-6 OLR and  $OLR_{CLR}$  climatologies with those of CERES EBAF Edition 2.8 and MERRA-2
- Inter-comparison of select AIRS Version-6 geophysical parameters affecting OLR with those of MERRA-2
- AIRS Version-6 confirms that 2015 was the warmest year on record and that the Earth's surface is still warming

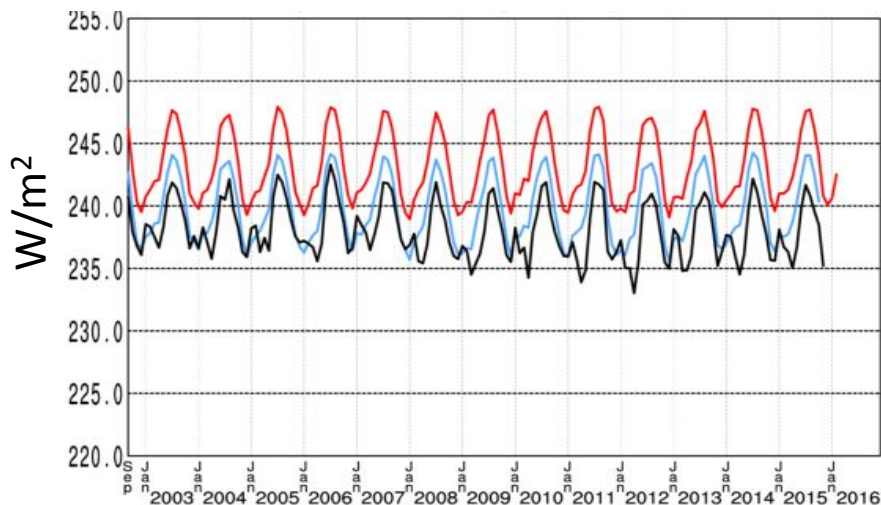
Agreement of AIRS OLR products with those of CERES tends to validate both sets of independently derived satellite products. Comparison of MERRA-2 products with those of satellite instruments indicates strengths and limitations of MERRA-2.

# OLR and Clear Sky OLR ( $OLR_{CLR}$ )

OLR is a critical component in assessing the Earth's radiation balance. CERES EBAF Edition-2.8 is considered the gold standard of OLR. CERES directly measures outgoing flux. The CERES Edition-2.8 products represent what OLR would have been if measured and averaged over a whole day. CERES  $OLR_{CLR}$  consists of the subset of CERES OLR measurements for those cases MODIS thought was clear. AIRS Version-6 OLR is a computed product using an OLR RTA in conjunction with AIRS retrieved products. AIRS Version-6  $OLR_{CLR}$  is computed using the same geophysical parameters, but assuming the cloud cover is zero. AIRS OLR Level-3 products are derived separately at 1:30 AM and 1:30 PM local time and averaged together. MERRA-2 OLR and  $OLR_{CLR}$  are computed analogously using MERRA-2 geophysical parameters. The daily MERRA-2 products are the average of the 0Z, 6Z, 12Z, and 18Z products.

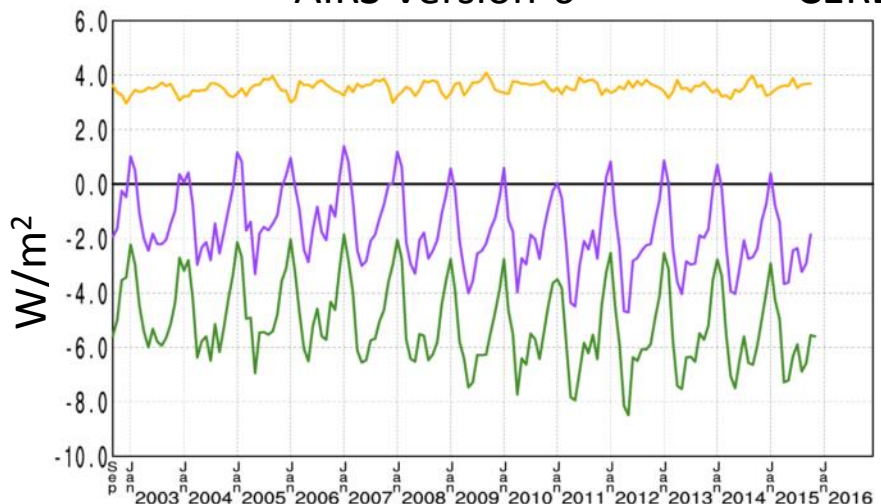
# Global OLR(W/m<sup>2</sup>)

September 2002 through February 2016



— AIRS Version-6

— CERES Edition-2.8



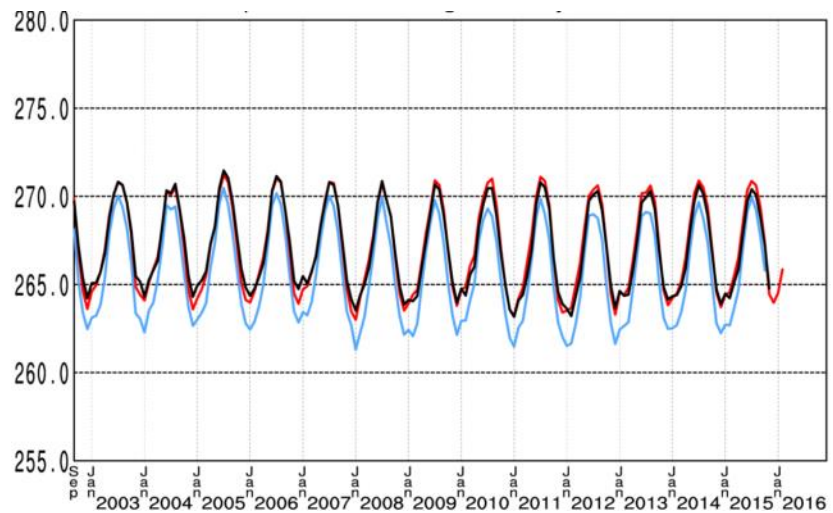
— AIRS minus CERES

— MERRA-2 CERES

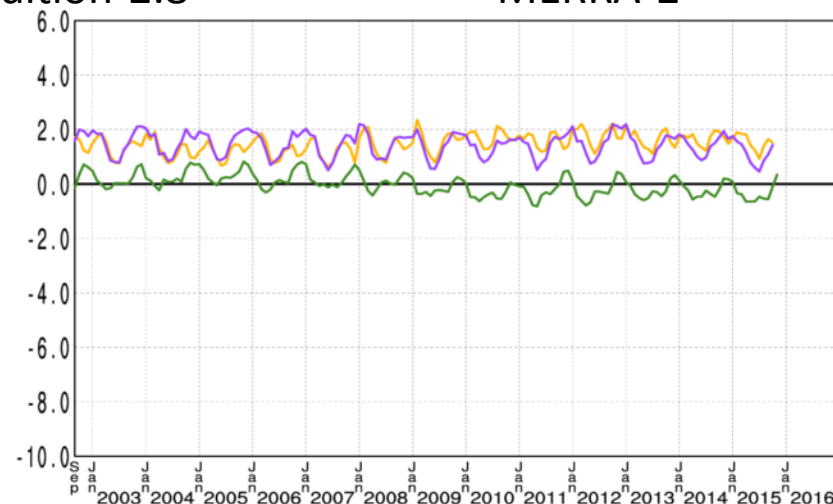
— MERRA-2 minus AIRS

AIRS and CERES OLR time series differ in time by a small constant value. MERRA-2 OLR agrees reasonably well with CERES but the differences have an annual cycle and a negative drift. MERRA-2 Clear Sky OLR agrees better with AIRS than with CERES, but also has a small negative drift.

# Global Clear Sky OLR (W/m<sup>2</sup>)



— MERRA-2



## Comparison of AIRS, CERES, and MERRA-2 OLR Time Series September 2002 through August 2015

	AIRS minus CERES	MERRA-2 minus CERES	MERRA-2 minus AIRS
<b>Global OLR</b>			
Bias ( $\text{W/m}^2$ )	3.534	-1.632	-5.166
Slope ( $\text{W/m}^2/\text{yr}$ )	0.0086 $\pm$ 0.0091	-0.1014 $\pm$ 0.0560	-0.1100 $\pm$ 0.0604
STD ( $\text{W/m}^2$ )	0.215	1.366	1.476
<b>Global Clear Sky OLR</b>			
Bias ( $\text{W/m}^2$ )	1.475	1.444	-0.030
Slope ( $\text{W/m}^2/\text{yr}$ )	0.0380 $\pm$ 0.0149	-0.0183 $\pm$ 0.0188	-0.0563 $\pm$ 0.0137
STD ( $\text{W/m}^2$ )	0.378	0.447	0.385

The AIRS OLR time series agrees extremely well with CERES in term of slopes and STD, but is biased high by  $3.5 \text{ W/m}^2$ . MERRA-2 OLR has decreased in time relative to both AIRS and CERES. AIRS, CERES, and MERRA-2 Clear Sky OLR time series are all sampled differently in space, but agree reasonably well with each other. CERES Clear Sky OLR samples only clear cases and differs the most from either AIRS or MERRA-2, which sample most, or all, cases respectively.

# Climatologies

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We constructed monthly AIRS, CERES, and MERRA-2 climatologies by taking the average value of the products for that month for the 13 consecutive years:

Sept 2002 – Sept 2014

Same for Oct, Nov, Dec

Jan 2003 – Jan 2015

Same for Feb-August

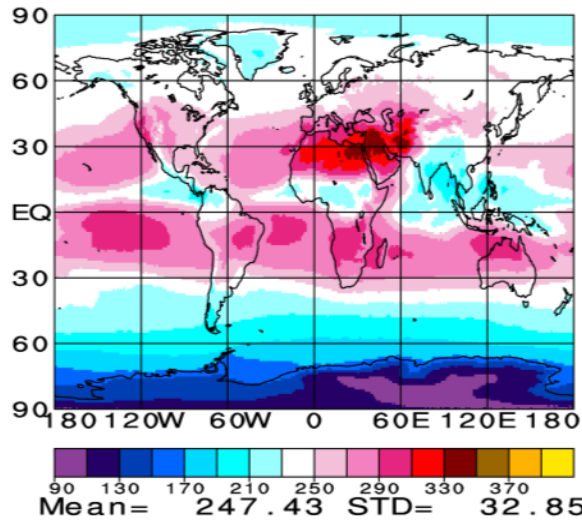
The grid point anomaly for a month in a given year is the value of the product for that month minus its climatology.

The Average Rate of Change (ARC) of a product is the slope of the linear least squares fit to the anomaly time series.

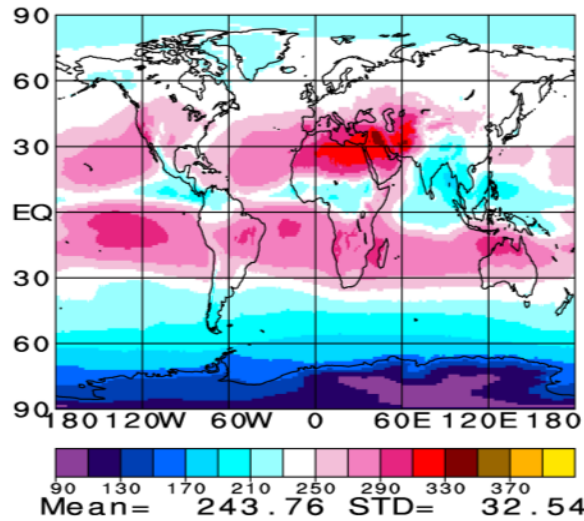
The El Niño Correlation (ENC) is the correlation of the anomaly time series with our El Niño Index (ENI), given by the NOAA Niño 3.4 SST minus its climatology as computed over the same 13 consecutive years.

# Outgoing Longwave Radiation (Watts/m<sup>2</sup>) July Climatology 2002 through 2015

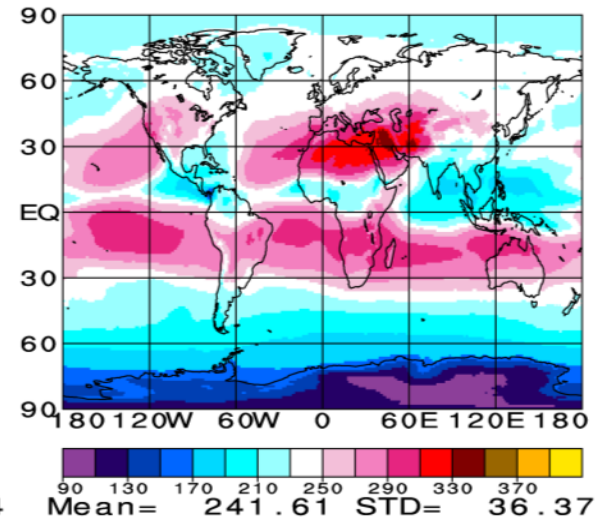
AIRS



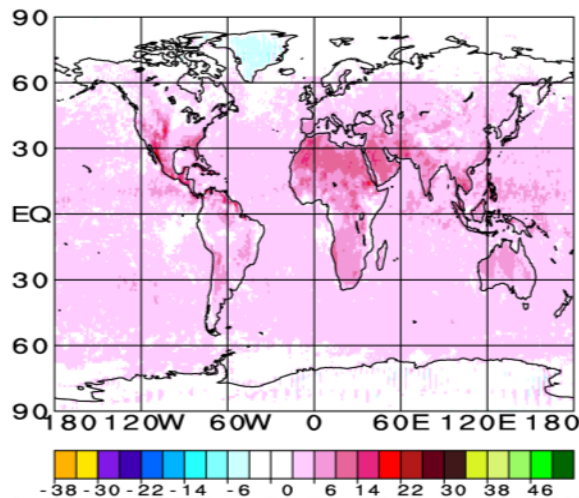
CERES



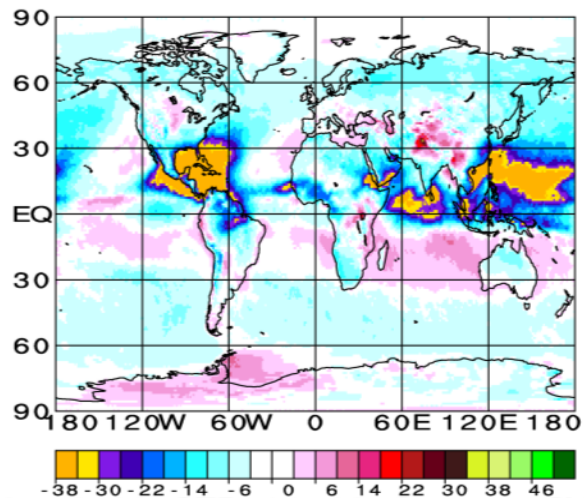
MERRA2



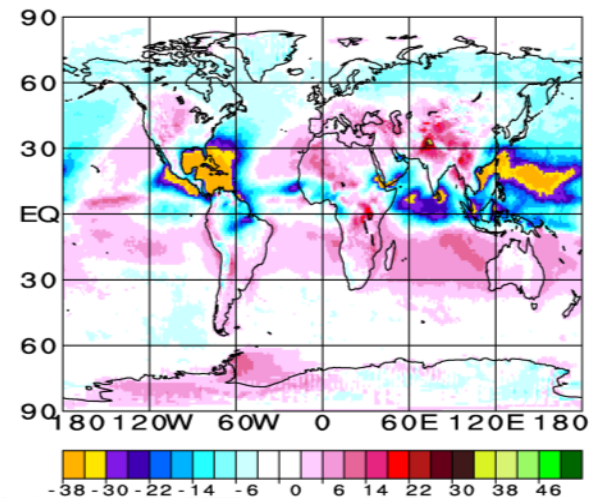
AIRS minus CERES



MERRA2 minus AIRS



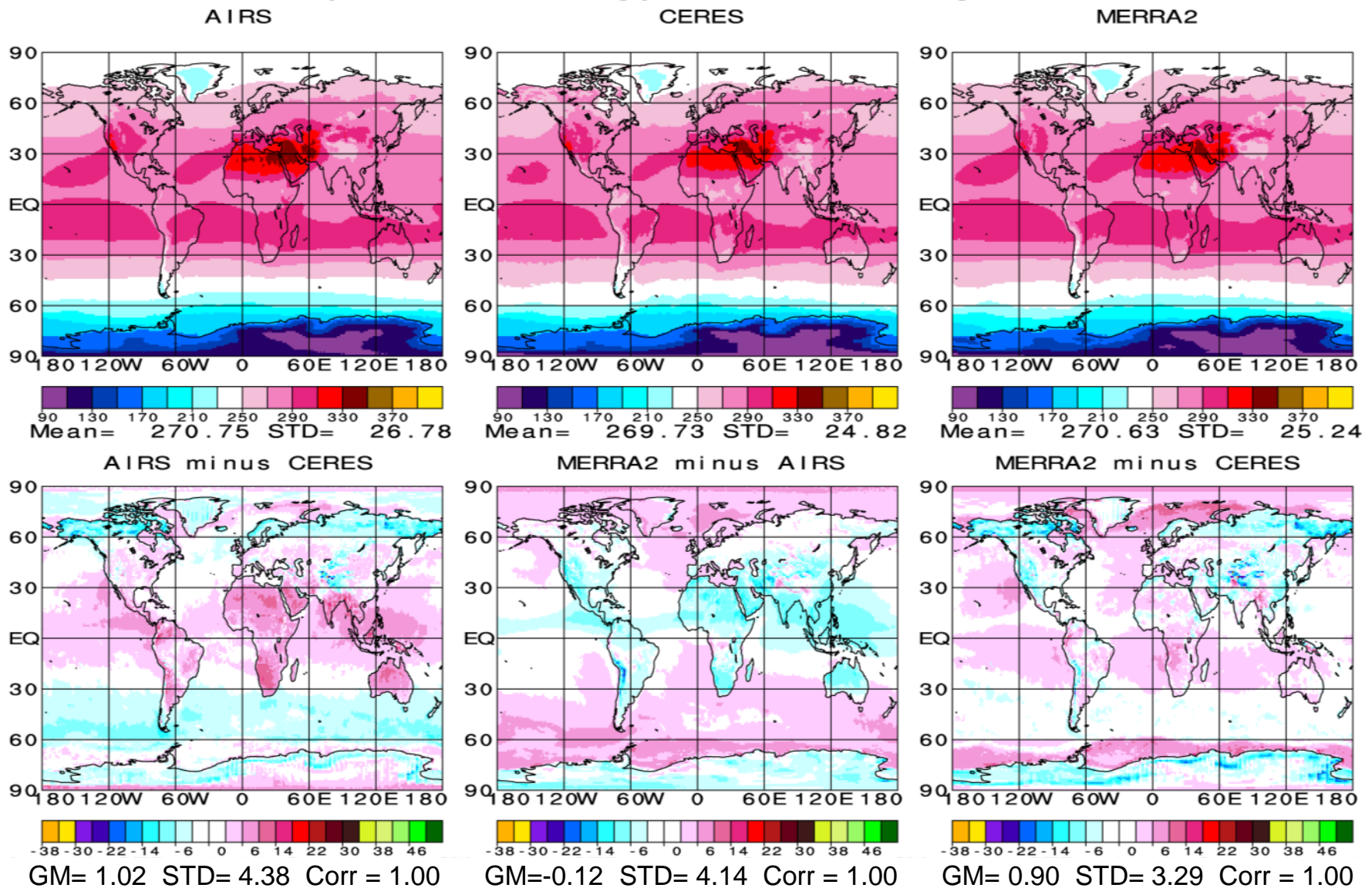
MERRA2 minus CERES



AIRS, CERES, and MERRA-2 July OLR climatologies agree reasonably well with each other in terms of spatial patterns and global mean. Tropical MERRA-2 OLR is too low compared to CERES in cloudy regions with low OLR, and too high in clearer regions where OLR is high.



# Clear Sky Outgoing Longwave Radiation (Watts/m<sup>2</sup>) July Climatology 2002 through 2015

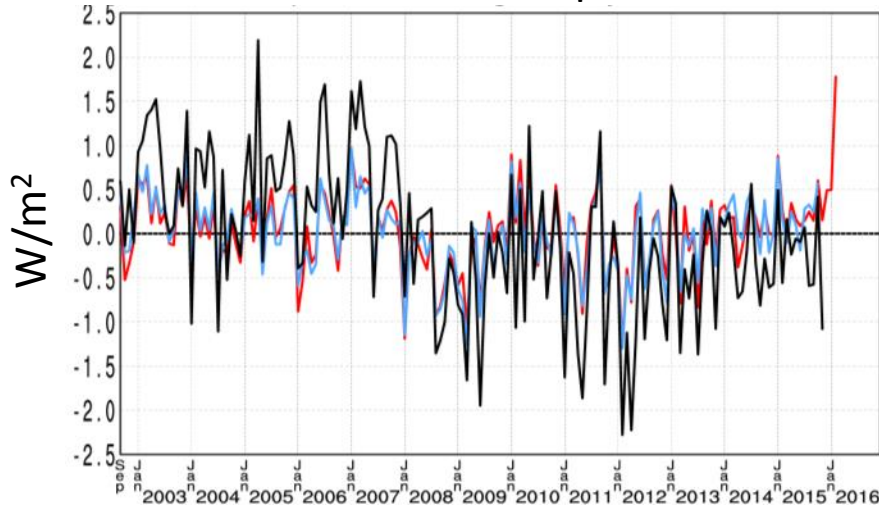


July AIRS, CERES, and MERRA-2 Clear Sky OLR climatologies agree reasonably well with each other. This implies that the major factor degrading MERRA-2 tropical OLR has to do with cloud effects. AIRS and CERES Clear Sky OLR climatologies have poorer agreement spatially than did OLR. This is a result of different spatial sampling.

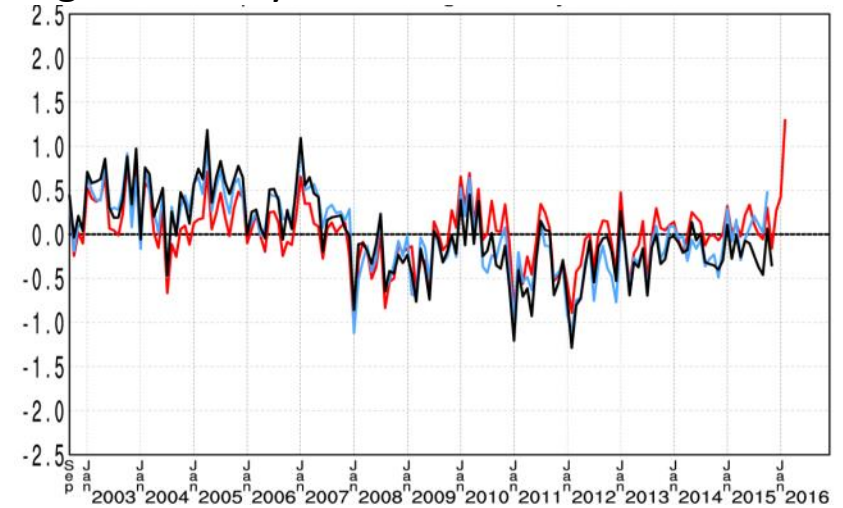


# Global OLR Anomaly (W/m<sup>2</sup>)

September 2002 through February 2016



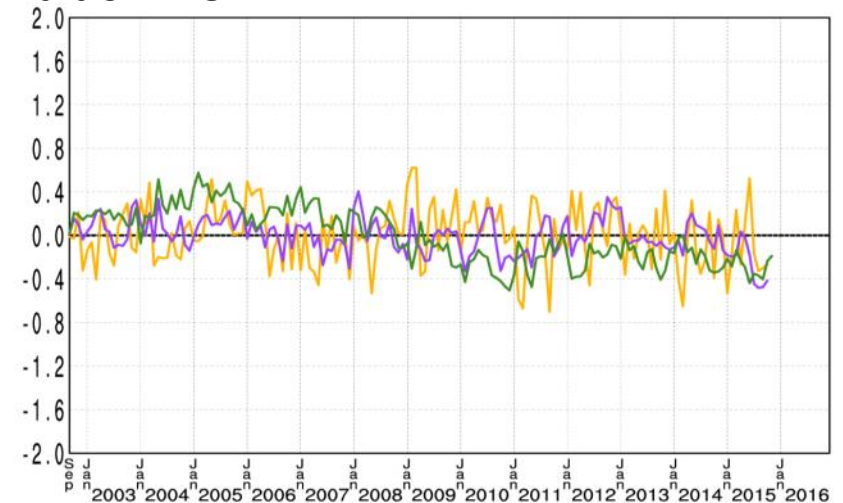
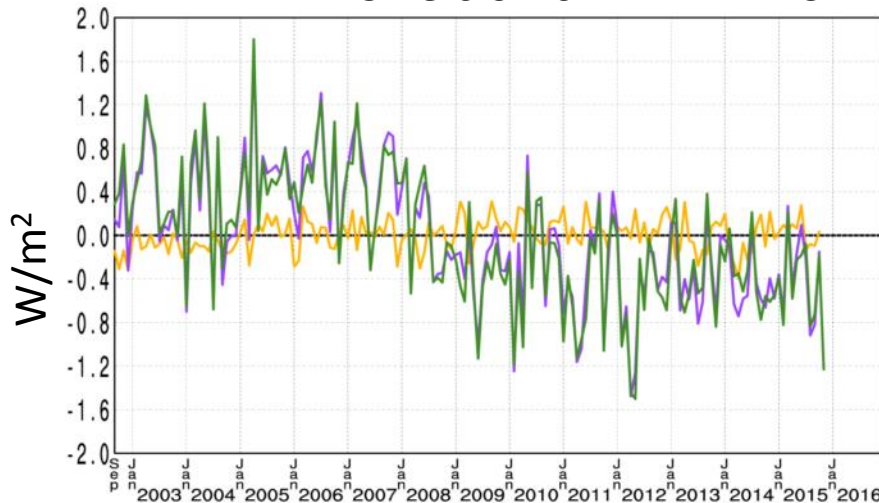
# Global Clear Sky OLR Anomaly (W/m<sup>2</sup>)



— AIRS Version-6

— CERES Edition-2.8

— MERRA-2



— AIRS minus CERES

— MERRA-2 CERES

— MERRA-2 minus AIRS

AIRS and CERES OLR anomaly time series agree extremely well with each other. MERRA-2 OLR anomalies are well correlated temporally with those of AIRS and CERES, but the MERRA-2 anomalies tend to be larger. All Clear Sky OLR anomaly time series are similar in time to those of OLR, but tend to be smaller.

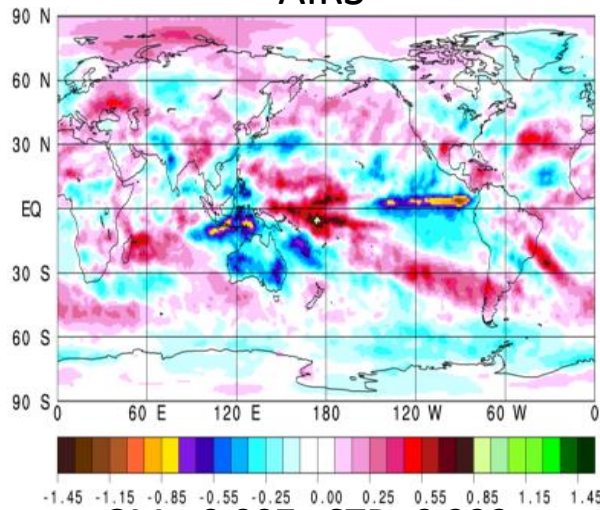
## Comparison of AIRS, CERES, and MERRA-2 OLR Anomaly Time Series September 2002 through October 2015

	AIRS minus CERES	MERRA-2 minus CERES	MERRA-2 minus AIRS
<b>Global OLR</b>			
Slope (W/m <sup>2</sup> /yr)	0.0073 ± 0.0061	-0.0891 ± 0.0200	-0.0964 ± 0.0200
STD (W/m <sup>2</sup> )	0.148	0.586	0.602
Correlation	0.947	0.831	0.803
<b>Global Clear Sky OLR</b>			
Slope (W/m <sup>2</sup> /yr)	0.0386 ± 0.0081	-0.0140 ± 0.0066	-0.0526 ± 0.0067
STD (W/m <sup>2</sup> )	0.242	0.167	0.256
Correlation	0.776	0.754	0.893

AIRS and CERES OLR anomaly time series agree extremely well with regard to ARCs (slopes), standard deviations, and correlation coefficients. AIRS and CERES OLR ARCs over this time period are essentially zero, considering their uncertainties. MERRA-2 has a spurious negative OLR trend and a poorer overall agreement with AIRS and CERES. AIRS and CERES Clear Sky OLR ARCs agree less well than do their OLR ARCs. This is a result of different spatial sampling.

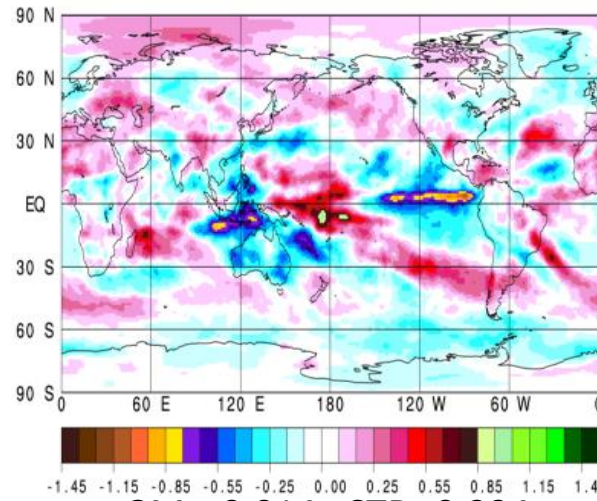
# OLR Average Rates of Change (ARCs) (W/m<sup>2</sup>/yr) September 2002 through October 2015

AIRS



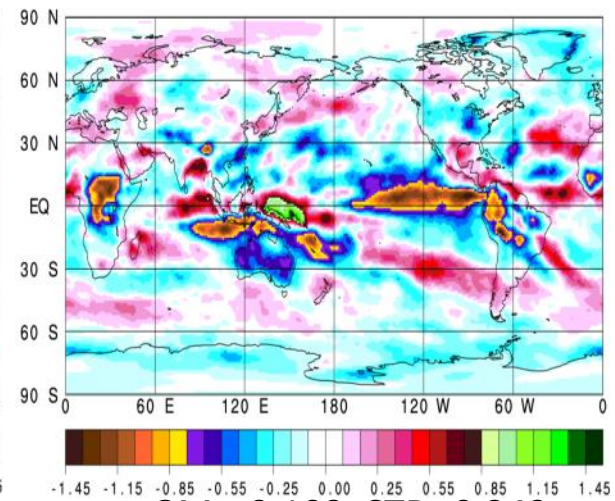
GM=-0.007 STD=0.229  
AIRS minus CERES

CERES

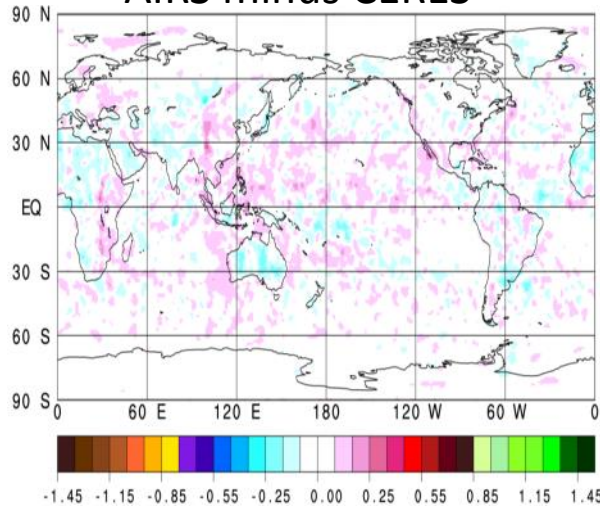


GM=-0.014 STD=0.234  
MERRA-2 minus AIRS

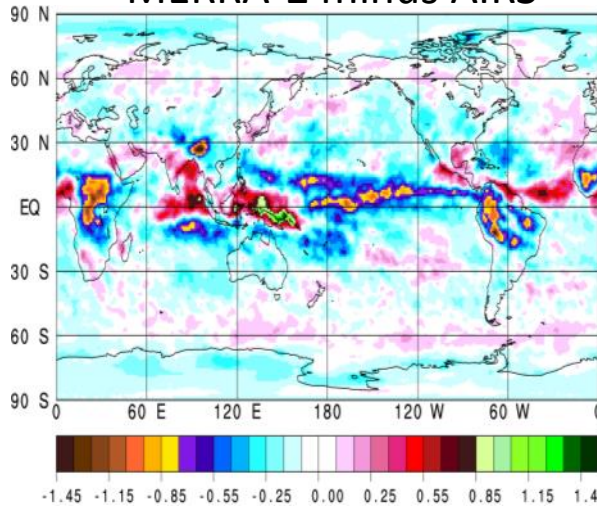
MERRA-2



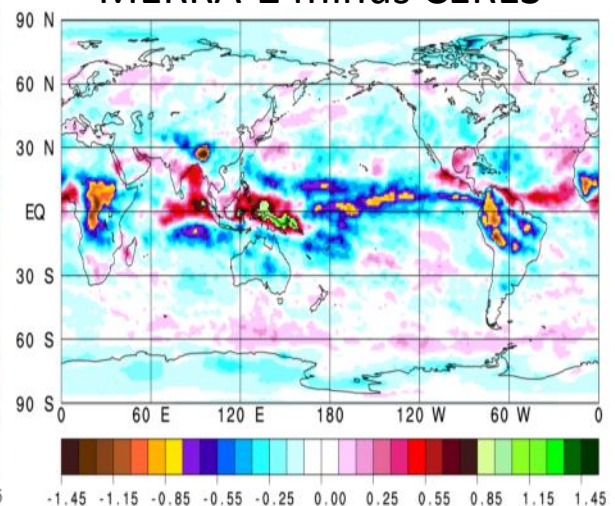
GM=-0.103 STD=0.343  
MERRA-2 minus CERES



GM=0.007 STD=0.056 Corr=0.970



GM=-0.096 STD=0.258 Corr=0.678



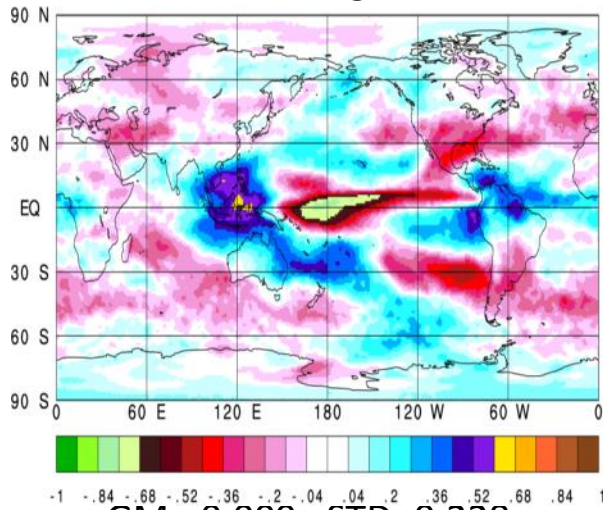
GM=-0.089 STD=0.253 Corr=0.696

AIRS and CERES OLR ARCs are very similar to each other in space. MERRA-2 OLR ARCs are similar in space to those of AIRS and CERES, but their magnitudes are too large in the tropics where OLR ARCs are dominated by El Niño/La Niña activity. In addition, the MERRA-2 OLR ARC is spuriously very negative over Central Africa.



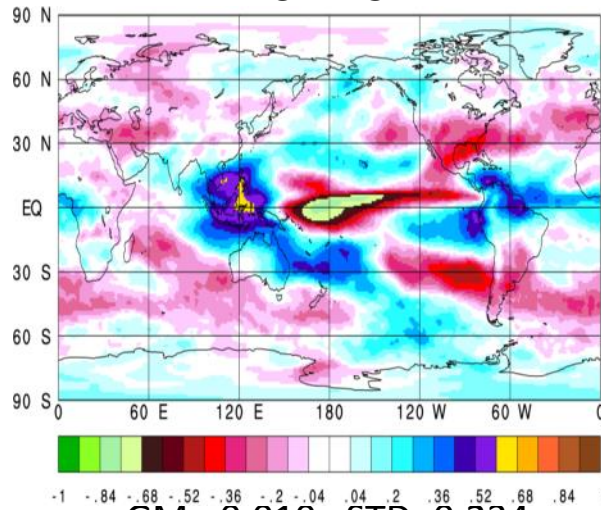
# OLR El Niño Correlations (ENCs) September 2002 through October 2015

AIRS



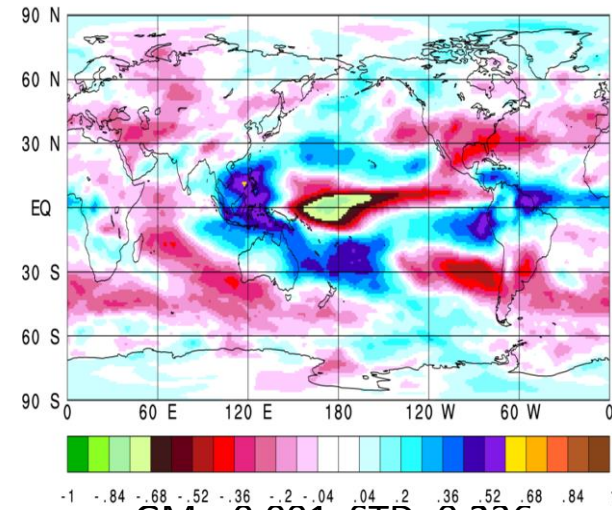
GM= 0.009 STD=0.228  
AIRS minus CERES

CERES

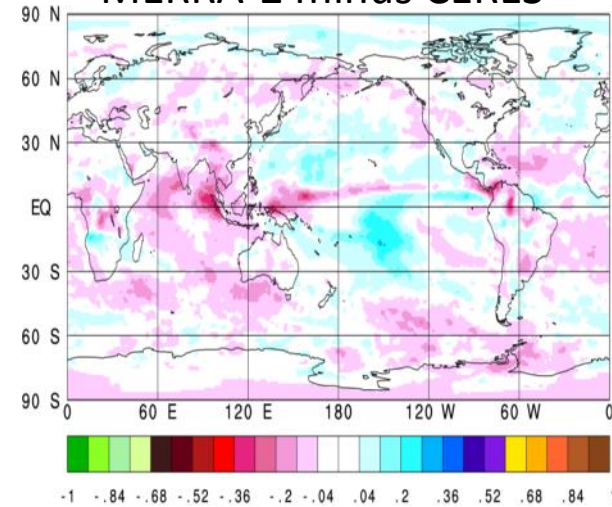
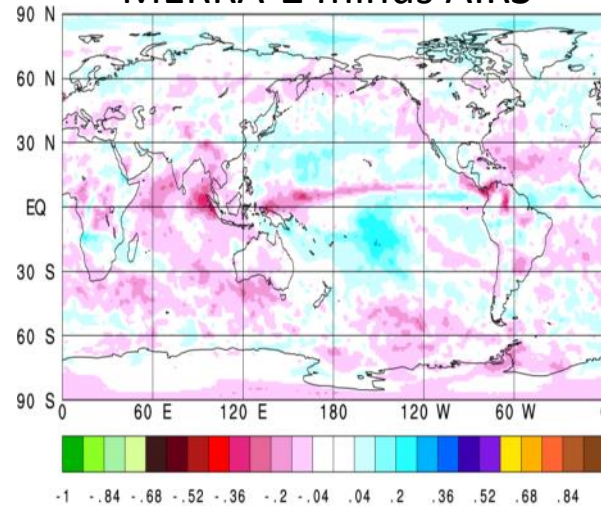
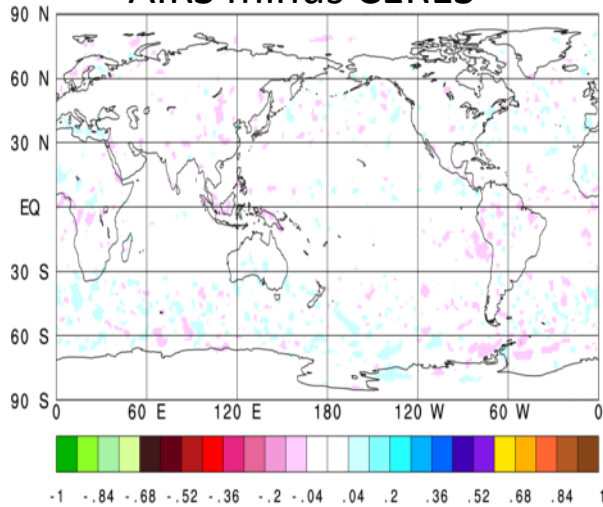


GM= 0.010 STD=0.234  
MERRA-2 minus AIRS

MERRA-2



GM=-0.001 STD=0.236  
MERRA-2 minus CERES



GM=0.001 STD=0.023 Corr=0.993

GM=-0.010 STD=0.075 Corr=0.935

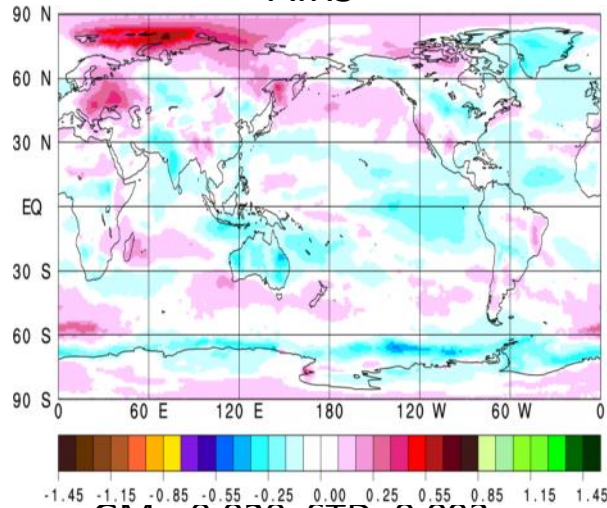
GM=-0.011 STD=0.074 Corr=0.941

AIRS and CERES OLR ENCs are likewise very similar to each other in phase and magnitude. This implies their anomaly time series agree well with each other. Tropical MERRA-2 OLR ENCs are in reasonable qualitative agreement with those of AIRS and CERES, but with measurable differences.

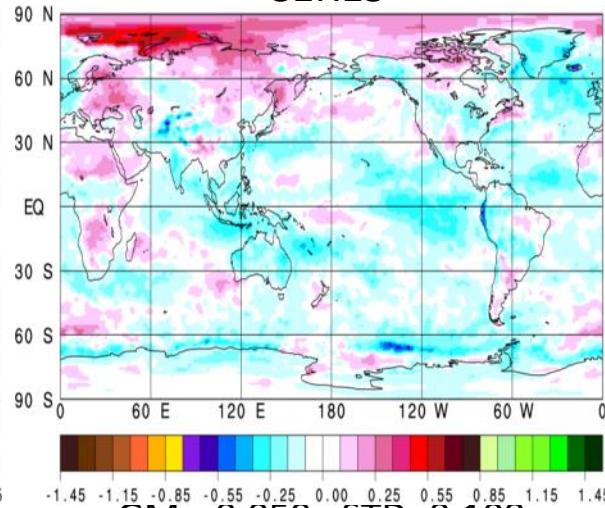


# Clear Sky OLR Average Rates of Change (ARCs) ( $\text{W/m}^2/\text{yr}$ ) September 2002 through October 2015

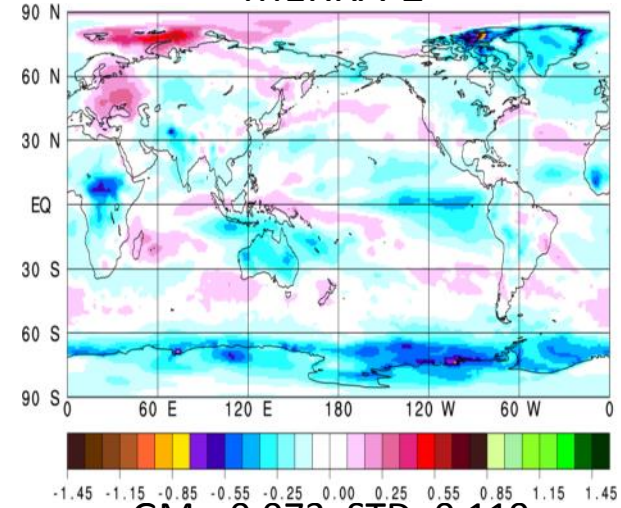
AIRS



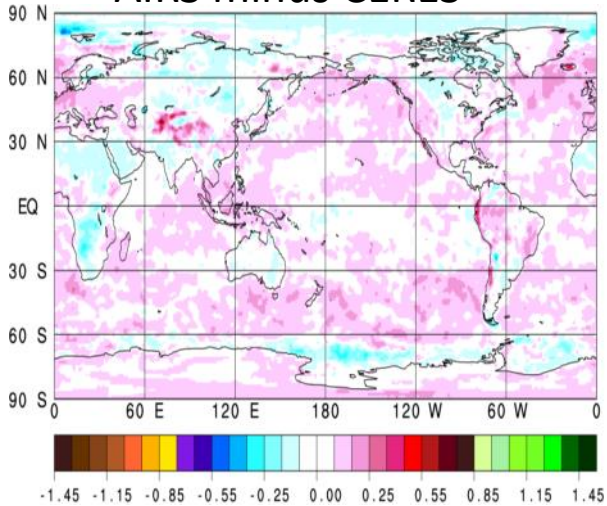
CERES



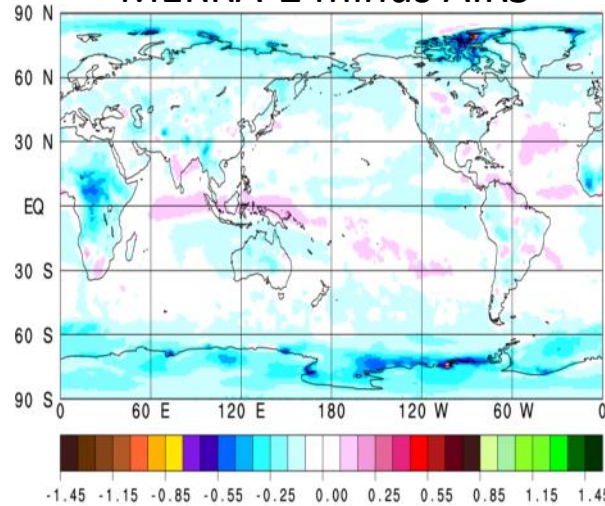
MERRA-2



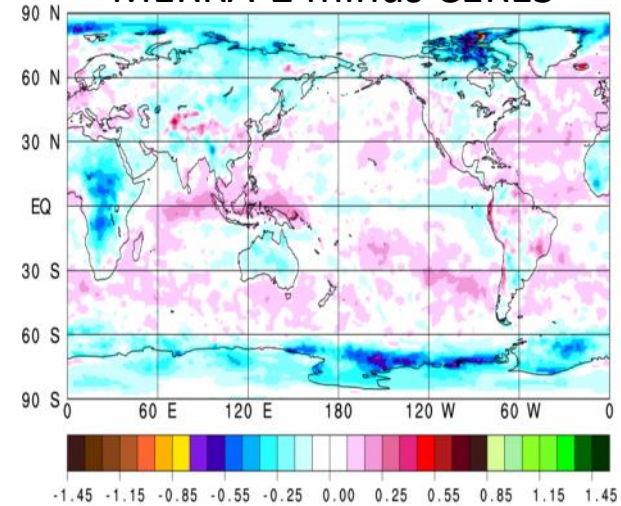
AIRS minus CERES



MERRA-2 minus AIRS



MERRA-2 minus CERES



As with OLR, AIRS Clear Sky OLR has not changed over the time period. CERES Clear Sky OLR has decreased however, and MERRA-2 has decreased more than CERES, especially at high latitudes and over Central Africa.

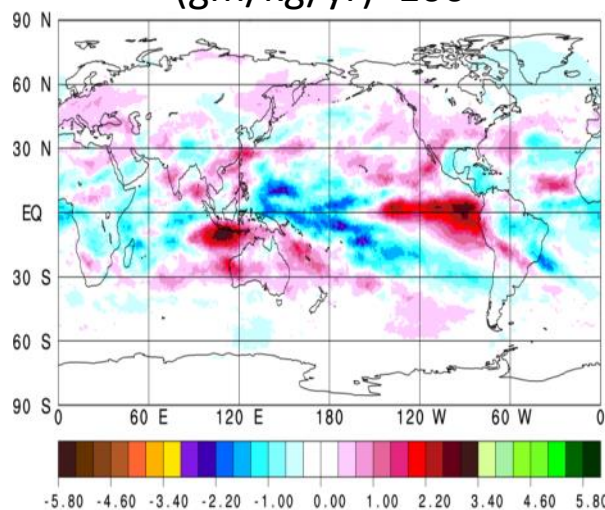
# Sensitivity of OLR to Geophysical Parameters

- OLR decreases with increasing amount of cloud cover  $\alpha\epsilon$  especially that of high clouds.
- OLR decreases with increasing amount of mid-upper tropospheric water vapor,  $q(p)$ , especially in the tropics.
- OLR increases with increasing  $T_{skin}$  and  $T(p)$ , especially at high latitudes.

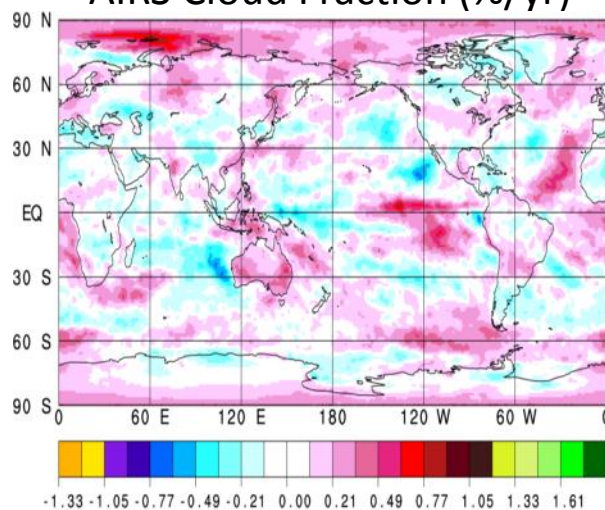
The following material compares ARCs of AIRS and MERRA-2 anomaly time series of  $\alpha\epsilon$ ,  $q(500)$ ,  $T_{skin}$ , and  $T(p_s)$ .



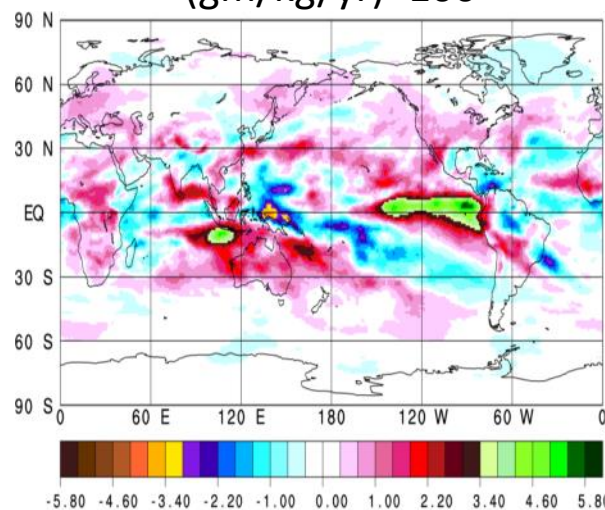
**Average Rates of Change (ARCs) September 2002 through October 2015**  
**AIRS 500 mb Specific Humidity MERRA-2 500 mb Specific Humidity MERRA-2 minus AIRS**  
**(gm/kg/yr)\*100 (gm/kg/yr)\*100**



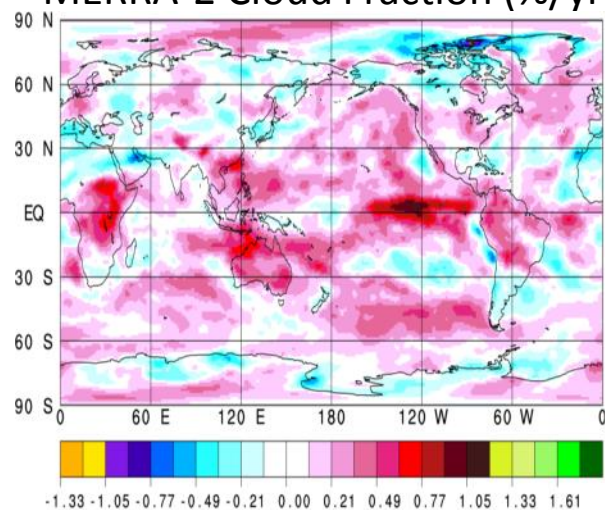
**GM=-0.021 STD=0.715**  
**AIRS Cloud Fraction (%/yr)**



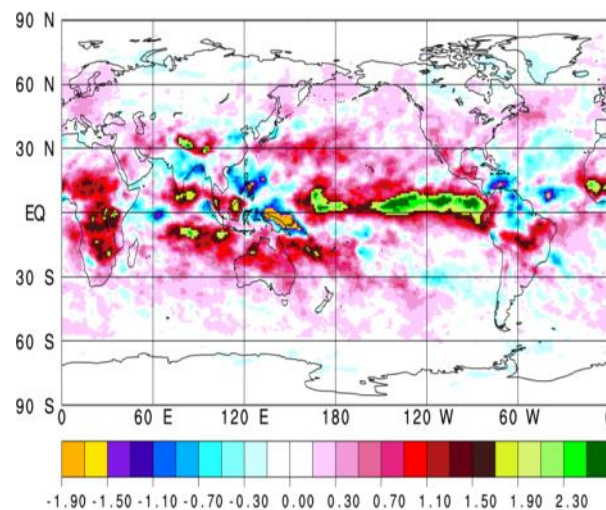
**GM= 0.035 STD=0.176**



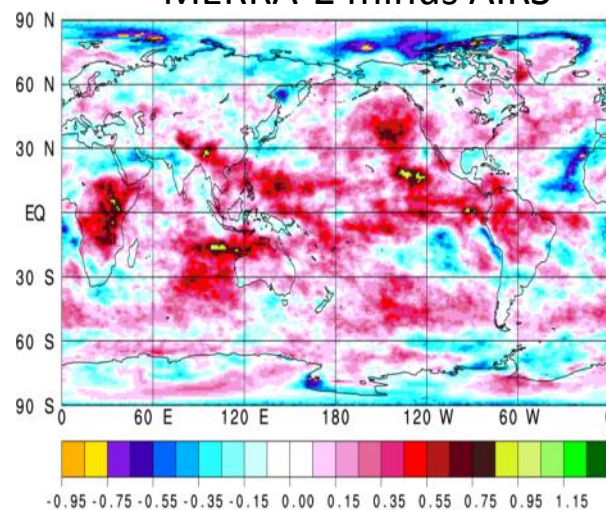
**GM=0.199 STD=1.046**  
**MERRA-2 Cloud Fraction (%/yr)**



**GM= 0.127 STD=0.231**



**GM=0.220 STD=0.576 Corr=0.833**  
**MERRA-2 minus AIRS**

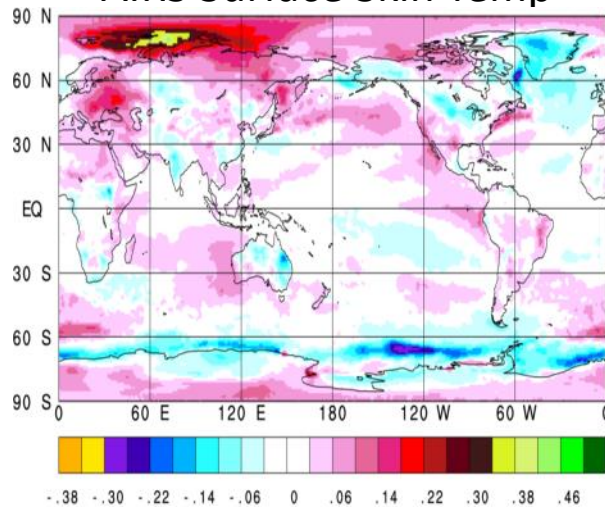


**GM= 0.092 STD=0.231 Corr=0.281**

The patterns of AIRS and MERRA-2 ARCs of 500 mb specific humidity are similar, but with some important differences. As with OLR, the biggest ARCs are in the tropics and MERRA-2 ARCs are larger than those of Version-6. MERRA-2 has a spurious increase in both global mean cloud cover and specific humidity, including a spurious increase over Central Africa. These changes contribute to the discrepancies in MERRA-2 OLR ARCs.

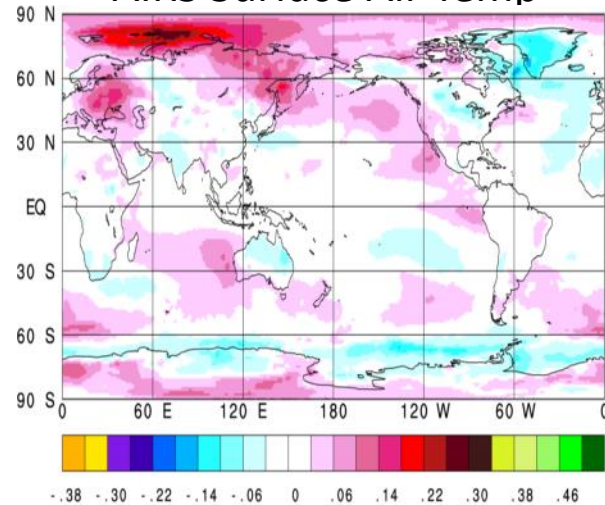


# Average Rates of Change (ARCs) September 2002 through October 2015 (K/yr)

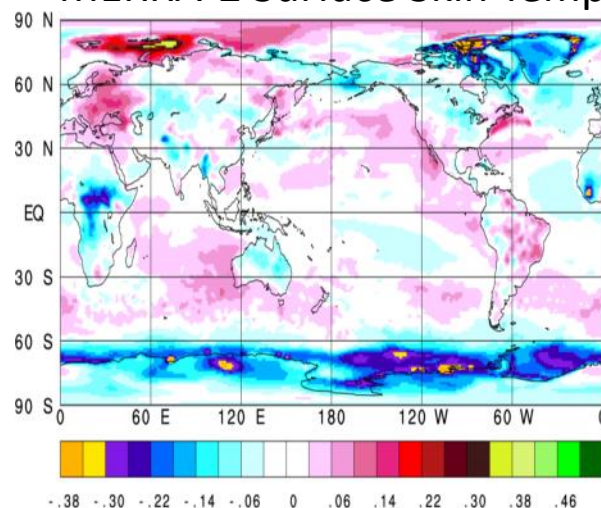


GM= 0.011 STD=0.038

AIRS Surface Air Temp

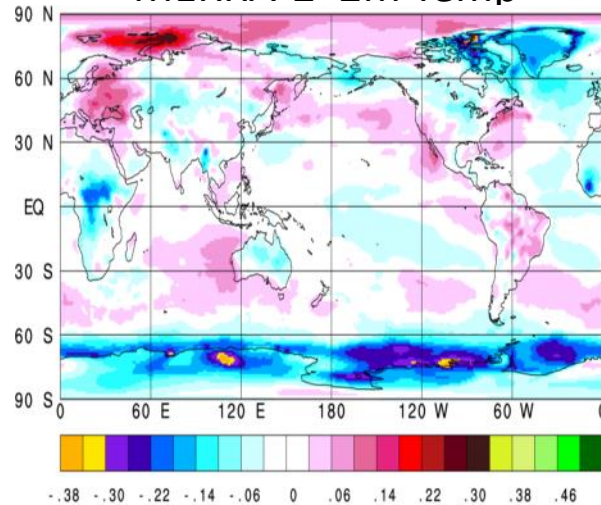


GM= 0.011 STD=0.030

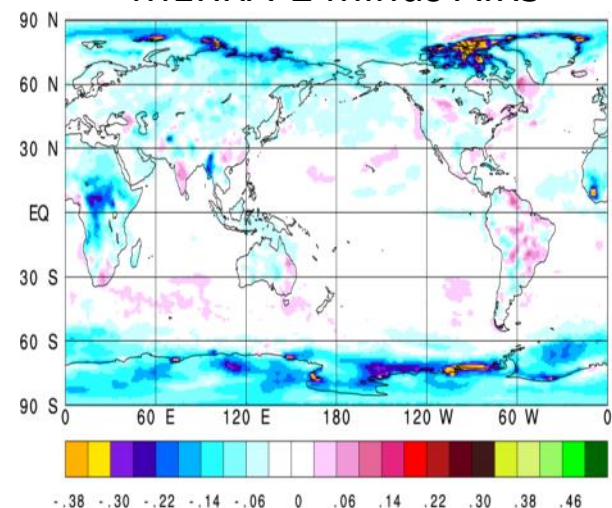


GM=-0.009 STD=0.052

MERRA-2 2m Temp

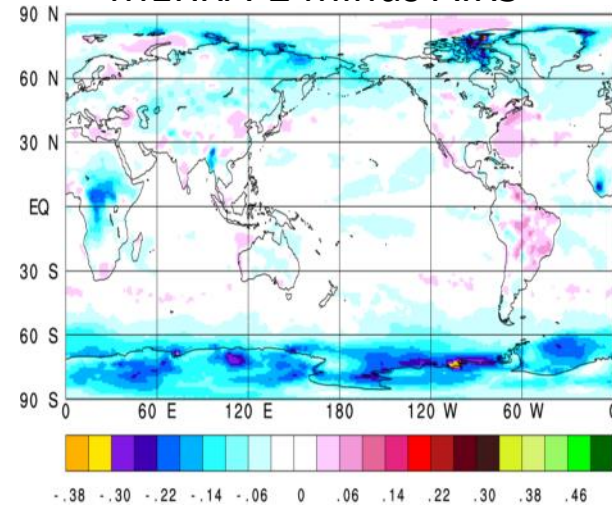


GM=-0.011 STD=0.048



GM=-0.020 STD=0.039 Corr=0.668

MERRA-2 minus AIRS

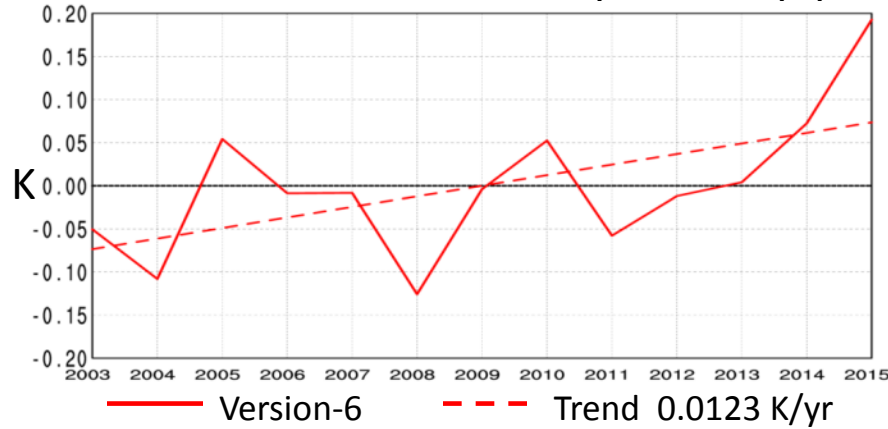


GM=-0.022 STD=0.036 Corr=0.676

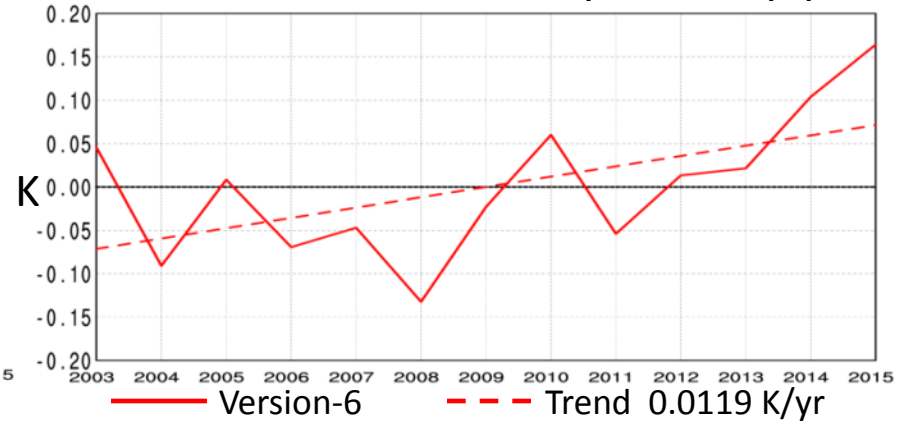
AIRS and MERRA-2 ARCS of surface skin temperature and surface air temperature are all similar to each other in general appearance. ARCs of MERRA-2 surface skin temperature and surface air temperature are more negative than those of AIRS at high latitudes and over Central Africa. This results in an apparent small global warming in AIRS and global cooling in MERRA-2.

# AIRS Version-6 2015 Annual Mean minus Average of 2003 through 2015

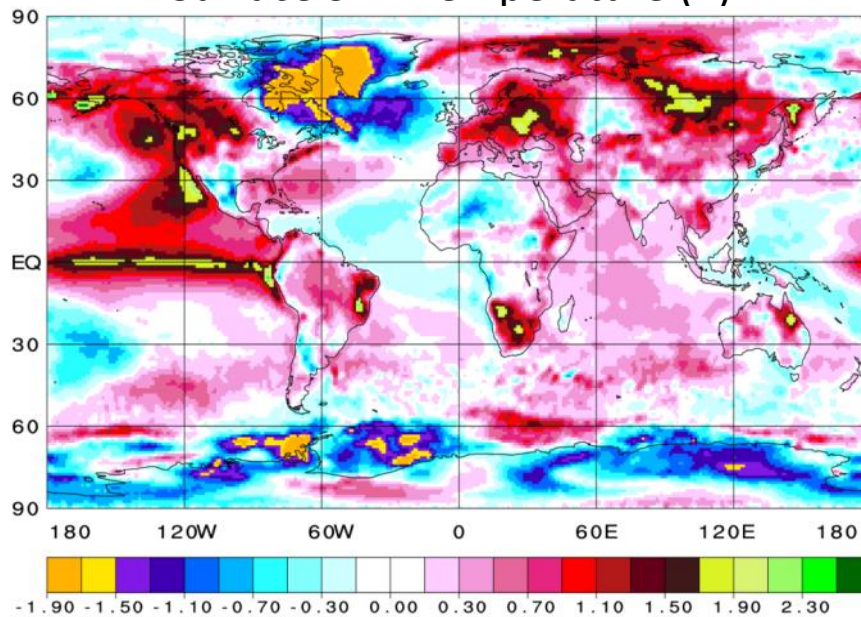
## Global Surface Skin Temperature (K)



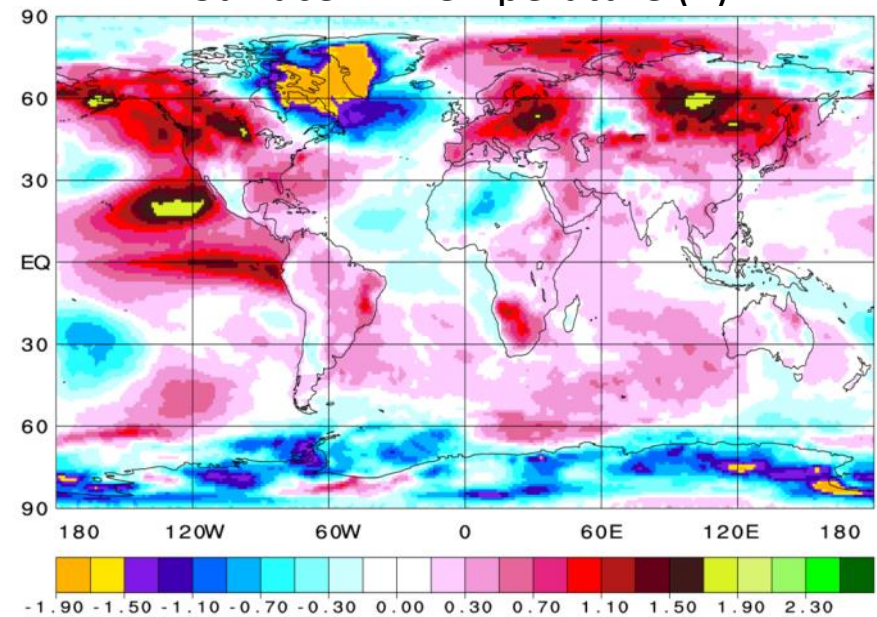
## Global Surface Air Temperature (K)



## Surface Skin Temperature (K)



## Surface Air Temperature (K)



AIRS Version-6 confirms that 2015 is the warmest year on record at the surface. Patterns of surface skin temperature and surface air temperature trends are similar in space and time. "Global mean" warming does not mean everywhere has warmed. Note Greenland and Antarctica.

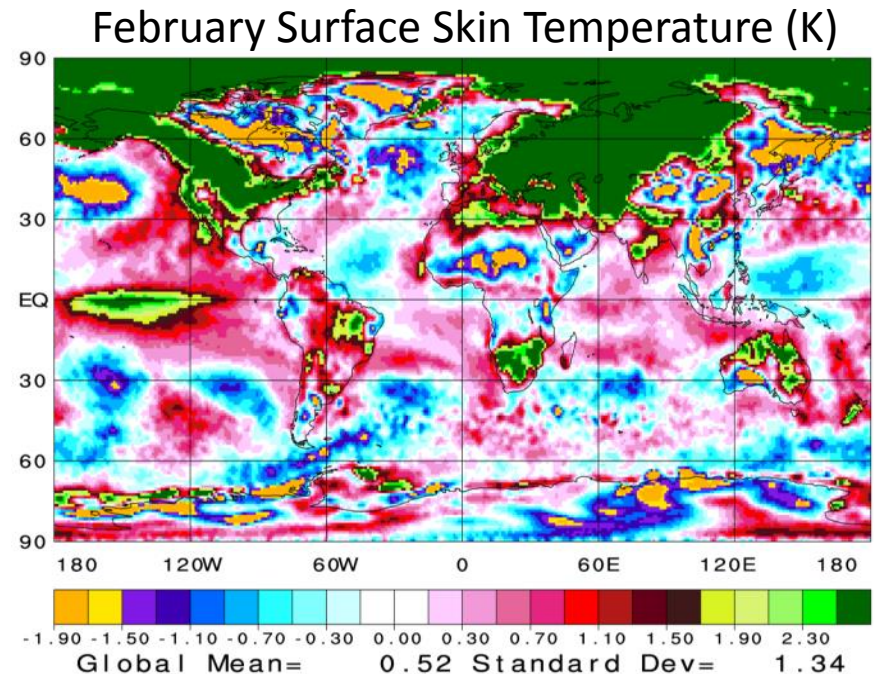
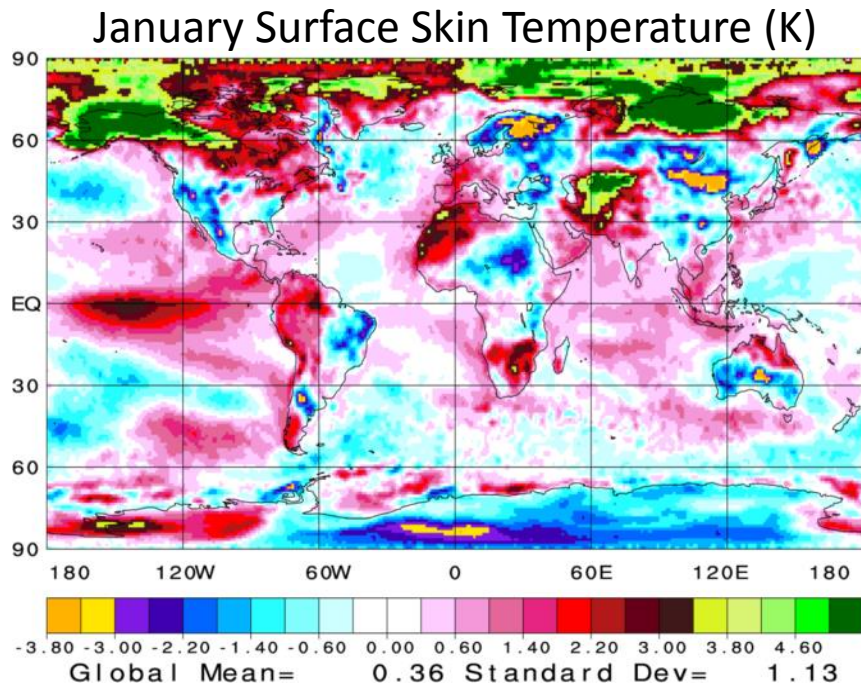
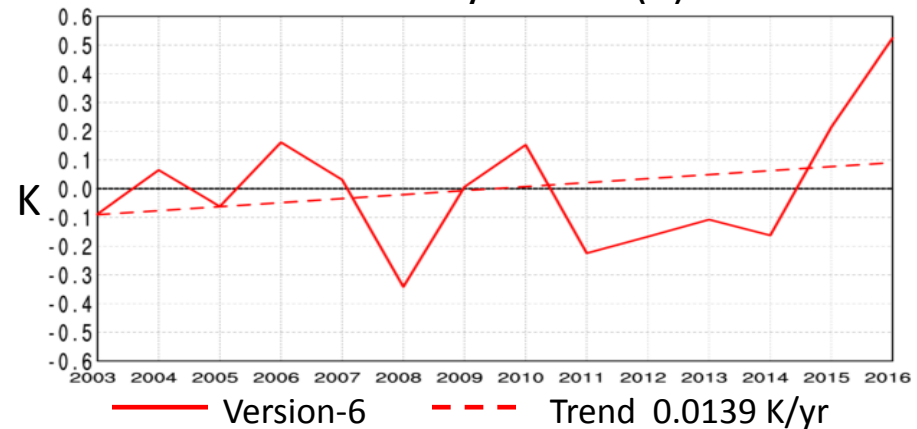
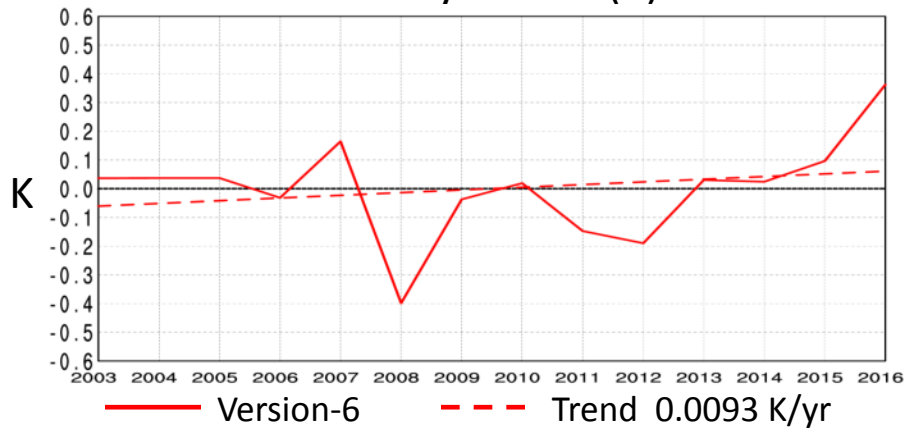


# AIRS Version-6 Surface Skin Temperature

## Single Month of 2016 minus Average of 2003 through 2016

### January Global (K)

### February Global (K)



AIRS Version-6 confirms that January and February 2016 have been the warmest on record. Monthly mean differences from climatology are much larger than that of annual mean differences.

# OLR Intercomparisons

The AIRS Version-6 global mean OLR time series agrees extremely well with CERES Edition-2.8 both in terms of absolute value and anomaly time series. AIRS OLR is higher than CERES by roughly  $3.5 \text{ W/m}^2$ . This bias, which is nearly constant in space and time, is within the uncertainty of the CERES OLR measurement. Both AIRS and CERES OLR time series show that there has been an essentially zero trend in OLR over the 13 year period Sept. 2002 – Oct. 2015. This tends to validate trends of all our parameters.

MERRA-2 OLR agrees reasonably well with CERES spatially and in the global mean sense, but MERRA-2 OLR is too low in convective regions in the tropics and too high elsewhere. The global mean MERRA-2 OLR time series shows a spurious negative trend. This is a result of major differences in tropical OLR trends, including a large spurious negative trend over Central Africa.

All Clear Sky OLR time series agree reasonably well given sampling differences.

# AIRS and MERRA-2 Product Anomaly Time Series

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ARCs of AIRS and MERRA-2 500 mb specific humidity agree very well in terms of spatial patterns, but MERRA-2 ARCs are larger in magnitude and show a spurious moistening globally and over Central Africa.

AIRS and MERRA-2 fractional cloud cover ARCs agree less well with each other. MERRA-2 shows a spurious global mean increase in cloud cover that is not found in AIRS, including a large spurious cloud increase in Central Africa.

AIRS and MERRA-2 ARCs of surface skin and surface air temperatures are all similar to each other in patterns. AIRS shows a small global warming over the 13 year period, while MERRA-2 shows a small global cooling. This difference results primarily from spurious MERRA-2 temperature trends at high latitudes and over Central Africa.

These differences all contribute to the spurious negative global MERRA-2 OLR trend.

AIRS Version-6 confirms that 2015 is the warmest year on record and that the Earth's surface is continuing to warm.